Some New Developments in Active Noise Control

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Two Kinds of Cancellation:

● **Signal Separation:**
Example: Army HMMWV Noise Canceller

● **Active Cancellation:**
(Noise or Vibration)
Example: Cancel Interior Noise in Aircraft

Dr. Martinez's
Commonly Asked Questions *(and our answers)*

- What are we trying to accomplish?

  Effective multichannel noise cancellation.

- How is it done now, and with what limitations?

  SFR-SVD algorithm. Robust, effective but > computing.

- What is truly new in this approach which will remove current limitations and improve performance? By how much?

  Eliminates redundancies, ill-condition, permits accurate solution to filter equation, hence effective cancellation. Gain 15 - 20 dB vs. noise across band.

- If successful, what difference will it make?

  Has greatly improved noise cancelling performance.

Noise Cancellation: State of the Art
Excerpts from 1995 Navy SBIR Solicitation

"Active control of noise and vibration has received a great deal of attention and achieved a certain level of practicality. However, active control methods have some limitations and drawbacks that additional research and development efforts are needed . . .

"Most important, current control strategy needs to be extended to off-resonant, and broadband vibration and acoustic control."

Noise Cancellation: State of the Art
Excerpts from 1997 Air Force SBIR Solicitation

"Active Noise Control has advanced significantly in recent years, but most applications to date have addressed physical systems with relatively limited spatial or temporal complexity.

"For example, noise is reduced at a single headset location or only for small numbers of sources contributing narrowband or perhaps multi-tonal input."
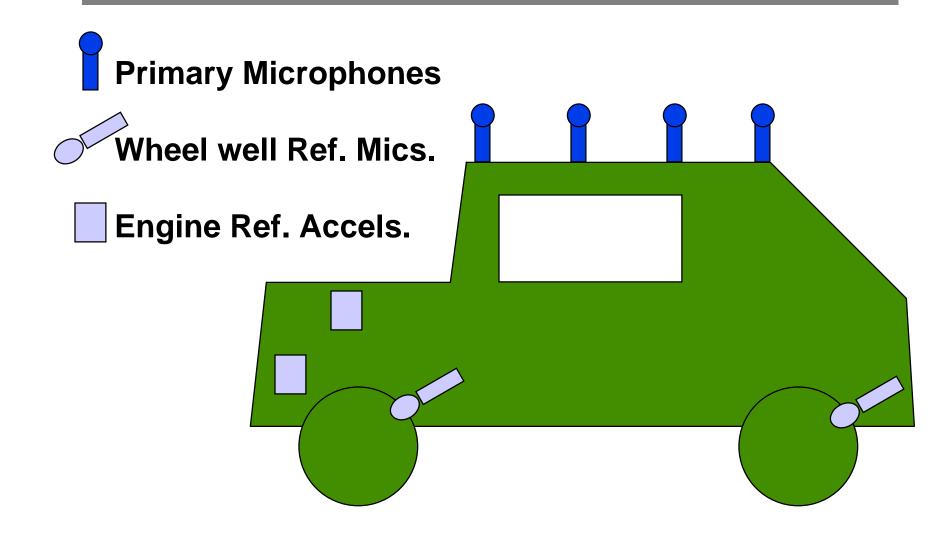
Noise Cancellation: State of the Art

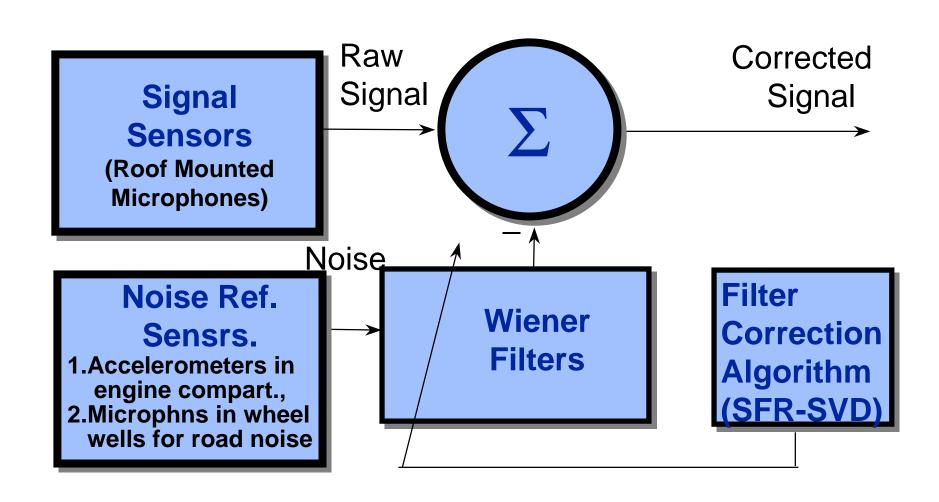**Excerpts from 1993 Army SBIR Solicitation:**

"Weapon platform and own-vehicle interference tend to degrade passive aero-acoustic sensor performance . . .

"ANC (Automatic Noise Cancellation) techniques such as the classic Widrow algorithm have been considered for cancellation of such interference, but . . . have not offered the degree of cancellation needed . . ."

HMMWV Instrumentation

Primary Microphones

Wheel well Ref. Mics.

Engine Ref. Accels.

Signal Separation: How It Works

Signal Sensors
(Roof Mounted Microphones)

Raw Signal

Σ

Corrected Signal

Noise

Noise Ref. Sensrs.
1. Accelerometers in engine compart.,
2. Microphns in wheel wells for road noise

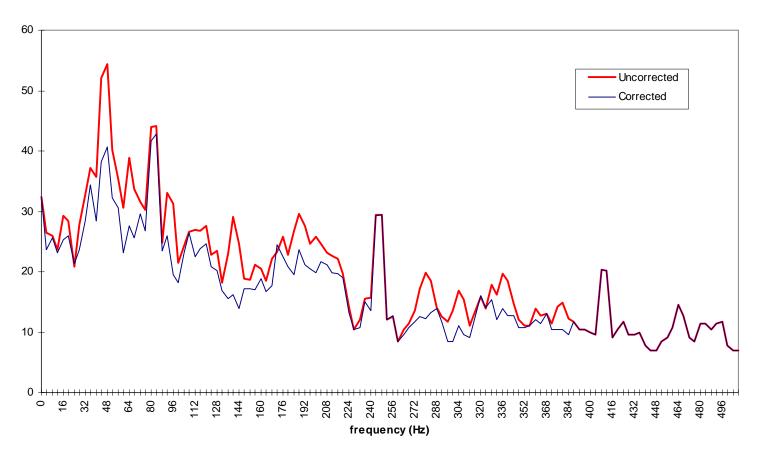**Wiener Filters**

Filter Correction Algorithm (SFR-SVD)

Proof of Concept

HMMWV Idling Using 5 Noise References

Power spectral density (dB)

Noise References:
Transmission fluid accelerometer
Valve Cover accelerometer
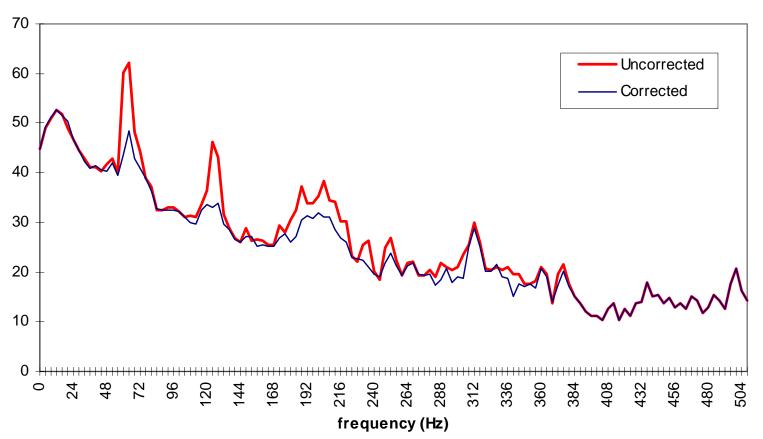Tailpipe accelerometer
Starter motor microphone
Alternator microphone

Signal:
82 Hz tone from loudspeaker
30 yards away

Signal Separation Technologies

Proof of Concept

HMMWV Moving at 10 mph, 5 Noise References

Power spectral density (dB)

Noise References: **No Signal**
Transmission fluid accelerometer
Valve Cover accelerometer
Tailpipe accelerometer
Starter motor microphone
Alternator microphone

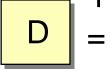Signal Separation Technologies

SVD Calculations

Filter Equation: $\quad R\, w = p \quad$ or $\quad w = R^{-1}\, p$

Diagonalize R with unitary U, $\quad R = U\, D\, U^\dagger$

where D is diag-onal.

$$D = \begin{bmatrix} d_{big1} & & \underline{0} \\ & d_{big2} & \\ \underline{0} & & d_{small} \end{bmatrix};$$

Pseudo-inverse: 0 **inst. of recip-rocal of** d_{small} .

$$D^{-1} = \begin{bmatrix} 1/d_{big1} & & \underline{0} \\ & 1/d_{big2} & \\ \underline{0} & & 0 \end{bmatrix} \leftarrow$$

Calculate w using pseudo-inverse of D:

$$w = U\, D^{-1}\, U^\dagger\, p$$

SFR-SVD Cancelling Algorithm

Ref. Sensor Measurements can be Redundant:

- Occurs when noise references exceed no. of effective noise sources

Such redundancies must be eliminated:

- Failure to do so degrades noise canceling performance.

SFR-SVD Method Eliminates Redundancies.

SFR-SVD has been thoroughly tested off-line:

- Army HMMWV Acoustic System: Engine, road noise reduced 20-30 dB;
- NASA aircraft Interior (active) Noise Reduction: 30 dB reduction;
- Navy towed array sonar: Accelerometers cancel vibration effects;
- Fetal electrocardiography: Maternal heatbeat removed.

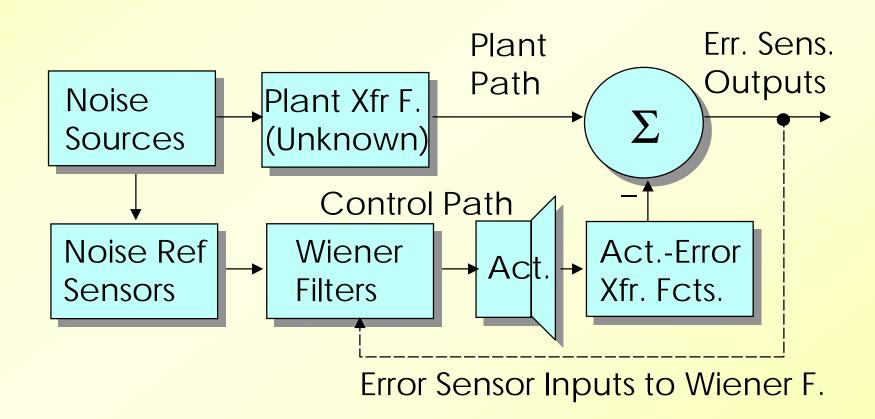**Army HMMWV Project is First time realtime:**

- Developing world's most capable multi-channel cancellation computer.

This information is covered by U.S. Patents 5,209,237, 5,917,919, and foreign patents.

Summary

- The LMS and FXLMS (for active control) algorithms do not work well in a multi-channel control scenario, either for signal separation or for active control.

- The SFR-SVD algorithm has been shown to overcome the problems of redundancy and ill-condition.

- A real-time signal separation controller built for the Army has been found to be extremely effective.

- Use of SFR-SVD for active control was tested off-line for NASA; work on a real-time active vibration controller continues under an NSF SBIR grant.

Feed-Forward Active Cancellation: How It Works

Noise Sources

Plant Xfr F. (Unknown)

Plant Path

Err. Sens. Outputs

Σ

Control Path

Noise Ref Sensors

Wiener Filters

Act.

$-$

Act.-Error Xfr. Fcts.

Error Sensor Inputs to Wiener F.

Proof of Concept

SFR-SVD Computer is Proven Technology

1995: Phase I SBIR: Off-line Tests Using Real Data from Army HMMWV Demonstrate SFR-SVD Method's Ability to Enable HMMWV Air Acoustic Sensor System.

1996-97: Phase II SBIR: SST Builds Real-time Signal Separation Noise Canceller.
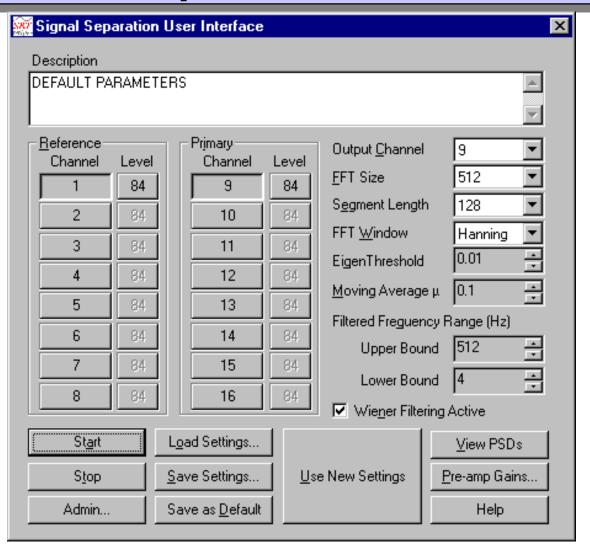
1997: Laboratory and HMMWV Field Tests Successful; Noise Canceller Performance Exceeds All Expectations; Final Report is Issued.

NSF Phase I SBIR: Application of SFR-SVD to Active Control of Vibrations.

1998: NSF Phase II SBIR: Active Control of Vibrations
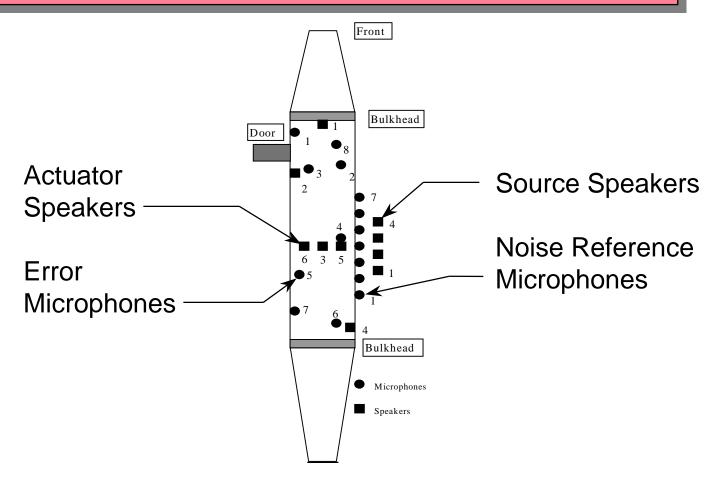**1999:** NSF Phase I SBIR: Noise Cancelling in Automotive environment.

Proof of Concept

The Graphic User Interface

Signal Separation User Interface

Description
DEFAULT PARAMETERS

Reference
Channel	Level
1	84
2	84
3	84
4	84
5	84
6	84
7	84
8	84

Primary
Channel	Level
9	84
10	84
11	84
12	84
13	84
14	84
15	84
16	84

Output Channel: 9
FFT Size: 512
Segment Length: 128
FFT Window: Hanning
EigenThreshold: 0.01
Moving Average μ: 0.1

Filtered Frequency Range (Hz)
Upper Bound: 512
Lower Bound: 4
☑ Wiener Filtering Active

Start | Load Settings... | Use New Settings | View PSDs
Stop | Save Settings... | | Pre-amp Gains...
Admin... | Save as Default | | Help

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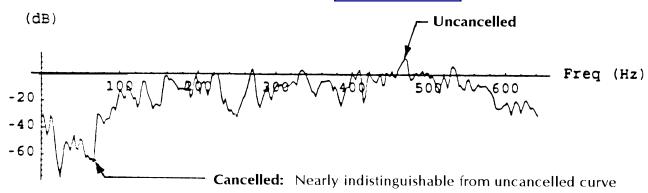# *Active Control of Noise/Vibration*

Active Noise Control in an Aircraft Fuselage
Experimental Setup

Active Control of Noise/Vibration

Active Noise Control in an Aircraft Fuselage
Comparison of Gains Achieved

➡ **Gain Against Noise When Using Classical LMS:**

Cancelled: Nearly indistinguishable from uncancelled curve

➡ **Gain Against Noise When Using SFR-SVD Method:**

Cancelled: Gain of 20 - 30 dB across the band